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of 2 to result in a 12.5% solution. The two solutions were put into the ultrasonic for 20 mins for homogenization. The two solutions were immobilized on the respective substrates of the silicalite-coated porous Ni alloy sheet in a manner similar to the above example. CO₂ separation performance of the immobilized sodium glycinate solution was tested using a feed gas of CO₂/O₂/N₂=15.3/5.3/bal at 71% RH. The results obtained under steady state conditions are plotted in FIGS. 22a and 22b. The support structure, 12.5% immobilized salt solution, and 25% immobilized salt solution were tested at room temperature (23° C.), while the 12.5% immobilized salt solution was also tested at 80° C. Again, the disclosed membrane showed excellent ability to immobilize the liquid fluid to withstand pressure gradients. The liquid fluid was intact under 3-bar pressure gradient at both temperatures used in this example.

As can be seen in FIGS. 22a and 22b, the bare support itself showed CO₂/N₂ selectivity factor as around 2. The separation factor was increased to about 10 with the immobilized salt membrane. The 12.5 and 25 wt % salt solutions showed similar CO₂/N₂ separation factors. However, CO₂ permeance of the 12.5 wt % is consistently higher than that of the 25 wt % at different pressure gradients. The selectivity factor of the immobilized 12.5 wt % salt solution was reduced at the higher separation temperature, while its CO₂ permeance was only increased slightly at the higher separation temperature. This example shows that the selectivity and CO₂ permeance of the membrane disclosed can be optimized by using appropriate CO₂-selective liquid fluids.

In view of the many possible embodiments to which the principles of the disclosed invention may be applied, it should be recognized that the illustrated embodiments are only preferred examples of the invention and should not be taken as limiting the scope of the invention. Rather, the scope of the invention is defined by the following claims. We therefore claim as our invention all that comes within the scope and spirit of these claims.

I claim:

1. A separation apparatus comprising:

- a membrane having a first side and a second side, the membrane capable of selective permeation of carbon dioxide from the first side to the second side of the membrane, the separation driven by a chemical potential gradient of carbon dioxide, the membrane comprising:
 - a macro-porous metallic substrate having a plurality of pores having a mean pore size of micrometers or sub-micrometer size and a porosity of from 35% to 70%;
 - a micro-porous and/or meso-porous modification layer, the modification layer comprising TiO₂, silica, ceria, γ-alumina, meso-porous solids impregnated with Ni, Fe, Ru, Cu, CuNi, Cu, Zn, Au, Pd, and mixtures thereof, modifying pore openings and/or modifying a surface chemistry on the first side of the porous metallic substrate, forming a permanent support structure;
 - a liquid fluid immobilized within pores of the modified metallic substrate; and
 - the liquid fluid capable of allowing carbon dioxide molecules to (i) selectively absorb relative to other types of molecules, (ii) be mobile in the liquid fluid, and (iii) desorb from the liquid fluid into a gas phase on the second side of the membrane.

2. The separation apparatus of claim 1, wherein the liquid fluid is stable under operating temperatures between -50 to 300° C.

3. The separation apparatus of claim 1, wherein the liquid fluid is an amine-based or carbonate-based solution.

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4. The separation apparatus of claim 1, wherein the liquid fluid comprises an amino acid salt solution or an ionic liquid.

5. The separation apparatus of claim 4, wherein the ionic liquid comprises an ammonium-based ionic liquid monomer and/or its corresponding polymers.

6. The separation apparatus of claim 1, wherein the porous metallic substrate is nickel, nickel alloy, titanium, and/or stainless steel.

7. The separation apparatus of claim 1, wherein the micro-porous modification layer has a mean pore size between 0.3 nm to 2 nm.

8. The separation apparatus of claim 1, wherein the meso-porous modification layer has a mean pore size between 2 nm to 50 nm.

9. The separation apparatus of claim 1, wherein the liquid fluid includes a catalyst comprising ZnCl₂, PdCl₂, CuCl₂, CrCl₂, Ni(PPh₃)₂Cl₂, and/or Ru complexes, the catalyst capable of facilitating a CO₂ absorption reaction.

10. The separation apparatus of claim 1, wherein an interior surface of the macro-porous metallic substrate is catalyzed with ZnCl₂, PdCl₂, CuCl₂, CrCl₂, Ni(PPh₃)₂Cl₂, Ni, Ru, Cu, CuNi, CuZn, Au, Pd, and mixtures thereof.

11. The separation apparatus of claim 1, wherein the modification layer comprises silicalite and ZSM-5 zeolite.

12. The separation apparatus of claim 1, wherein the liquid fluid is immobilized inside the pores of the modification layer and the thickness of the immobilized liquid fluid is less than 10 μm.

13. The separation apparatus of claim 1, wherein the liquid fluid is immobilized inside the pores of the metallic substrate at a thickness of less than 100 μm.

14. The separation apparatus of claim 1, wherein the porous metallic substrate has a thickness of equal to or less than 200 microns.

15. The separation apparatus of claim 1, wherein the membrane is capable of separating CO₂ in a feed gas mixture from a flue gas of fossil fuels, the feed gas mixture including CO₂, N₂, O₂, H₂O, SO₂, and NO molecules.

16. The separation apparatus of claim 1, wherein the chemical potential gradient of CO₂ is a partial pressure differential of CO₂.

17. The separation apparatus of claim 1, wherein the membrane is capable of separating CO₂ from a feed gas mixture when the membrane is subjected to a gas pressure of 1 bar or greater on the first side of the membrane and a gas pressure less than 1 bar on the second side of the membrane by the feed gas mixture.

18. The separation apparatus of claim 1, further comprising a plurality of the membranes arranged in parallel to form a membrane module capable of industrial-scale CO₂ gas separation with reduced pressure drops at large gas flow rates.

19. A method comprising:

- providing a membrane having a first side and a second side, and selectively permeating and separating carbon dioxide from the first side to the second side of the membrane, the separation driven by a chemical potential gradient of carbon dioxide, forming the membrane by providing a macro-porous metallic substrate having a plurality of pores having a mean pore size of micrometers or sub-micrometer size and a porosity of from 35% to 70%;

providing a micro-porous and/or meso-porous modification layer, the modification layer comprising TiO₂, silica, ceria, γ-alumina, meso-porous solids impregnated with Ni, Fe, Ru, Cu, CuNi, Cu, Zn, Au, Pd, and